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B. Kosciuk, V. Ravindranath, O. Singh and S. Sharma

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Contributed paper

Development and testing of stable supports for the National Synchrotron Light Source II RF beam position monitors

B. KOSCIUK†, V. RAVINDRANATH, O. SINGH AND S. SHARMA
NSLS-II Division, Brookhaven National Laboratory

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The National Synchrotron Light Source II currently under construction at the Brookhaven National Laboratory is expected to provide unprecedented orbit stability in the storage ring in order to fully utilize the very small emittance of the electron beam. The desire to measure the position of such small beams to high resolution imposes stringent requirements on the thermal and structural stability of the supports for the beam postion monitor (BPM) pick-up electrodes located on multi-pole vacuum chambers and more so on those located upstream and downstream of insertion device sources where the beam size is the smallest. Even with tunnel air temperature expected to be controlled to ±0.1°C, low coefficient of thermal expansion materials is required to meet this level of thermal stability. Here, we present the application of these materials to the design of stable supports for radio frequency (RF)-BPMs as well as the methods of testing their performance.

1. Introduction

The National Synchrotron Light Source II (NSLS-II), a third-generation medium-energy (3 GeV) storage ring is expected to produce world-leading levels of brightness, flux and beam stability over a very broad energy range extending from the far IR to the very hard X-ray region (NSLS-II Preliminary Design Report, 2008). In order to achieve this level of performance, very small emittances, both vertical and horizontal, are required and the electron beam is required to be stable in a position better than 10 % of the beam size. The most stringent case occurs in the short insertion device (ID) source where $\sigma_y \sim 3$ μm. The performance of the orbit feedback is ultimately limited by the beam postion monitor (BPM) noise (Guo). If we consider the noise floor of the BPMs to be the combination of electronic drift and mechanical stability, the maximum r.m.s. motion of the BPM pick-up electrodes must be at the sub-micron level. In this paper, we refer to BPMs located on multi-pole chambers as standard BPMs and those in the ID straight sections as user BPMs. Table 1 shows the mechanical and thermal stability requirements of both standard and user BPMs.

†Email address for correspondence: bkosciuk@bnl.gov

	Condition	Standard BPM, nm r.m.s. (vertical)	Standard BPM, nm r.m.s. (horizontal)	User BPM, nm r.m.s. (vertical)	User BPM, nm r.m.s. (horizontal)
Vibration	50–2000 Hz	10	25	10	25
	4–50 Hz	25	60	25	60
	0.5–4 Hz	200	200	100	100
Thermal	1 min to 8 h	200	500	100	250

TABLE 1. BPM stability requirements.

2. User BPM supports

Meeting the thermal stability requirement of ±100 nm was the most challenging aspect of the user BPM support. A composite carbon fibre tube was initially considered but ultimately rejected due to difficulties in manufacturing a tube with sufficient stiffness to meet the vibration requirements (Kosciuk). The final design utilized an array of four 50 mm diameter invar rods with steel spacer plates to give the structure high rigidity (figure 1*a*). The low diffusivity of invar and low surface area-to-volume ratio of the rods resulted in a temperature response of ±0.015°C to the ±0.1°C ambient air. This combined with the low coefficient of thermal expansion (CTE) of invar yielded an exceptionally high thermal stability in the order of ±50 nm, satisfying the requirement by a factor of 2.

Initial attempts to measure the thermal stability using a displacement transducer mounted on an insulated support proved to be futile. Ultimately, a laser interferometer in conjunction with an evacuated beam pipe proved to be a reliable method of measuring small displacements of large structures over long durations (figure 1*b*).

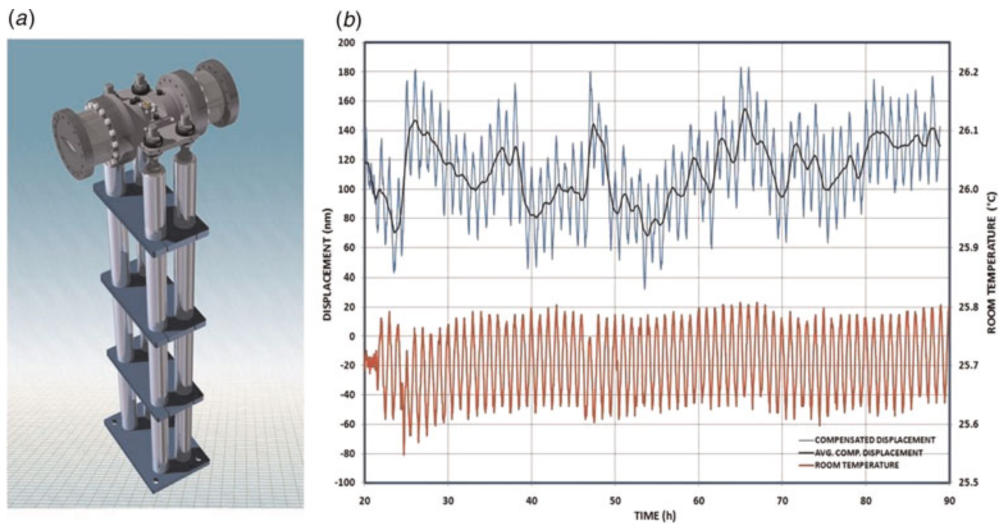

FIGURE 1. (*a*) User BPM support configuration, (*b*) thermal stability plot of invar user BPM support measured with a laser interferometer (blue curve) in response to ±0.1°C tunnel air (red curve) over a 90 h interval.

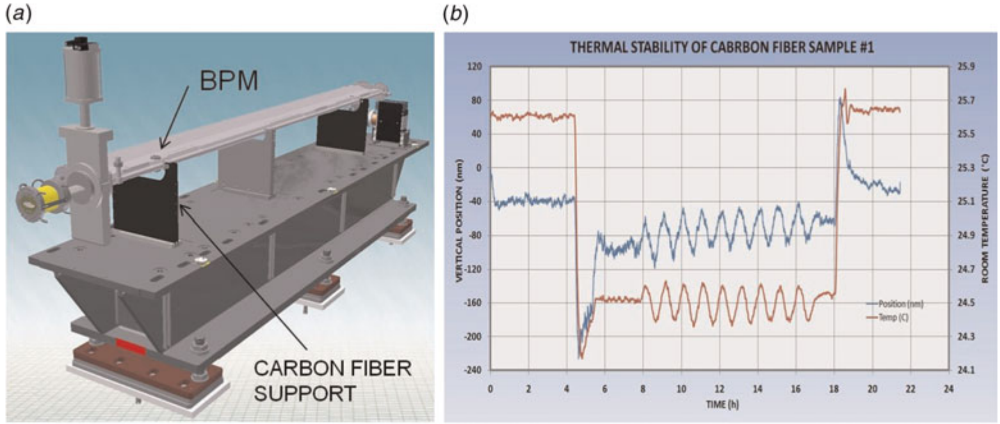

FIGURE 2. (*a*) Proposed standard BPM support configuration, (*b*) thermal stability performance of first article carbon fibre supports measured with a laser interferometer.

3. Standard BPM supports

The baseline design of the chamber mounted BPMs consists of thin invar plates to provide adequate thermal stability as well having flexibility to allow for bake-out of the multi-pole vacuum chambers. However, it was discovered that the high permeability of invar and the close proximity of these supports to the focusing magnets had a detrimental effect on field quality.

Currently under consideration is the use of composite carbon fibre supports of geometry similar to the baseline design (figure 2a). The low permeability of the carbon fibre mitigates the issue of field disturbance and can be engineered to have very low CTE, in the order of 1 μm/m-°C or better. In addition, incorporating high modulus fibre into the composite will give the final product adequate flexibility in the longitudinal direction to allow for bake-out and sufficient stiffness to absorb the loads induced by the chambers during survey and alignment. Of critical importance is the choice of epoxy used in the composite, in this case polyether ether ketone (PEEK) was chosen for its radiation hardness.

The first article supports were produced based on the above criteria and tested for thermal stability using laser interferometry. As the data plot in figure 2(*b*) shows, the vertical response to ±0.1°C tunnel air is ±30 nm. The vertical motion of the steel girder is expected to be of the order of ±100 nm, implying the total motion of the girder/chamber support system to be ±130 nm.

4. Conclusions

Given the storage ring (SR) tunnel ambient condition of ±0.1°C with 1 h cycling, the current design of the invar user BPM support meets the thermal stability requirement of ±100 nm by a factor of 2.

The use of composite carbon fibre instead of invar for the multi-pole chamber supports mitigates the issue of magnetic field disturbance and has a sufficiently low CTE to satisfy the thermal stability requirements of the standard BPMs. In addition, the carbon fibre has enough flexibility to absorb chamber deformation during bake-out and should have sufficient stiffness to absorb chamber loading during survey and alignment.

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